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PROJECT FOR PERFORMANCE OF REMEDIAL RESPONSE ACTIVITIES AT UNCONTROLLED HAZARDOUS SUBSTANCE FACILITIES—ZONE 1

NUS CORPORATION
SUPERFUND DIVISION

R-586-11-3-8

REPORT ON

GEOPHYSICAL STUDY
MEDLEY SITE
GAFFNEY, SOUTH CAROLINA

TDD NO. F4-8307-03

FOR THE

HAZARDOUS SITE CONTROL DIVISION
U.S. ENVIRONMENTAL PROTECTION AGENCY

NOVEMBER 18, 1983

NUS CORPORATION
SUPERFUND DIVISION

SUBMITTED BY	TECHNICAL REVIEW BY	APPROVED BY
Carol Thurmond	Charles H. Lee	Murray Warner
Carol Thurmond Geohydrologist	Charles Lee Geologist	Murray Warner, P.E. Regional Project Manager

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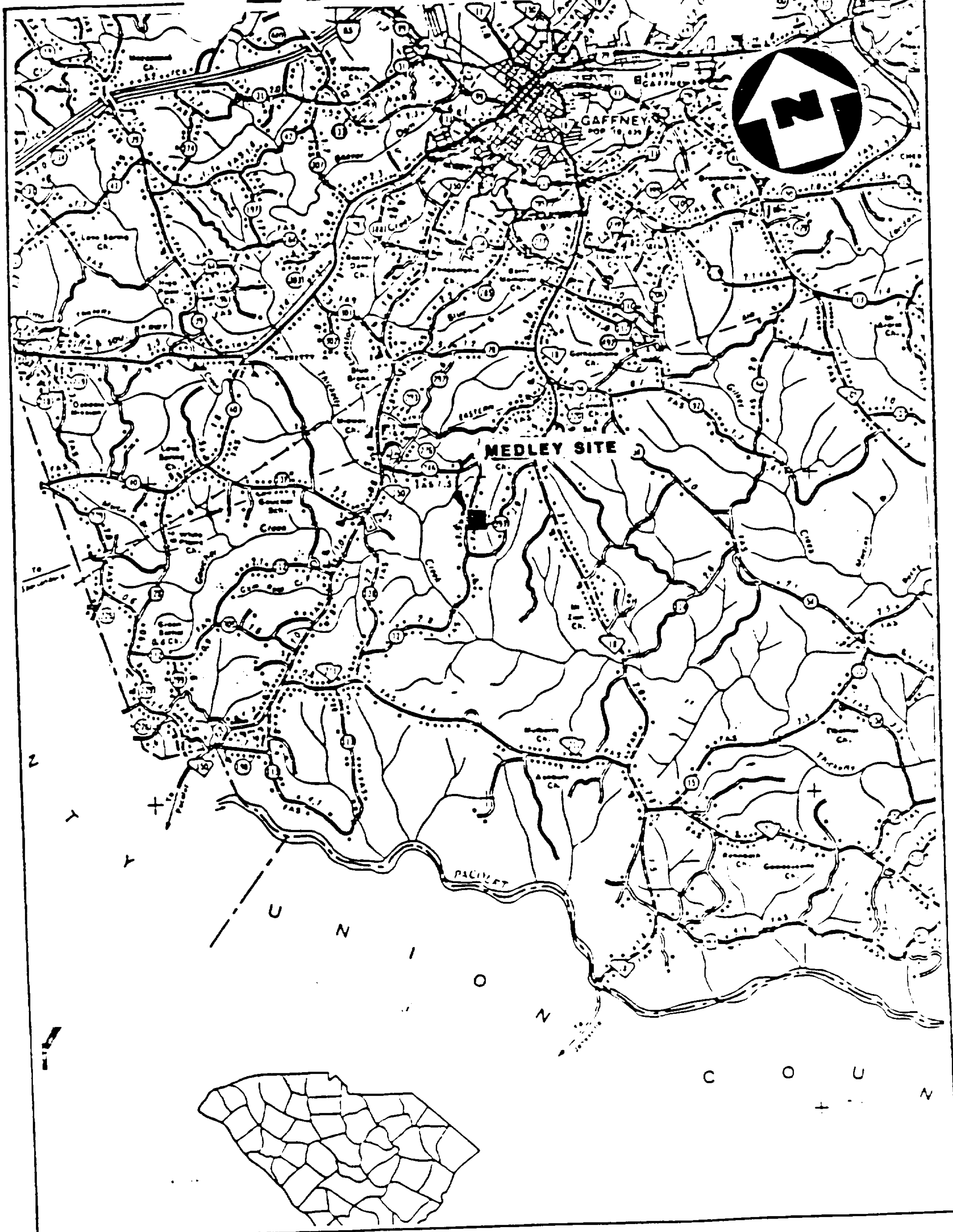
INTRODUCTION

The Medley Site is an approximately 7-acre chemical waste disposal site belonging to Mr. Ralph Medley. The site is located on County Road 72 off State Route 18 in Cherokee County, South Carolina, about six miles south of Gaffney, South Carolina (figure 1).

EPA conducted an emergency clean-up of the site during June and July, 1983. As a result of that effort, over 5,300 55-gallon drums and 15-gallon containers were removed from the site. Some drums contained wastes and some were empty. Six small lagoons onsite contained an estimated 70,000 gallons of water and an unknown volume of sludge and solid waste materials. The contents of the lagoons were treated and removed and the lagoons backfilled. Severely contaminated soils were also removed. Waste material removed from the site included industrial solvents, insoluble organics such as polyesters and resins, alcohols, acids, bases, and small amounts of polychlorinated biphenyls. The site presently has a graded dirt surface. Some contaminants are still present as evidenced by odors coming from the soil. Also, during this study leachate was observed coming from the site into a gulley to the southeast. This is the direction of dip of the rocks in the area, and thus, is the likeliest direction in which leachate would migrate.

The site is located in the Piedmont physiographic province of South Carolina. This province is characterized by metamorphic and igneous rocks, which are typically intensely deformed and commonly fractured and faulted. The main source of ground water is from such fractures in the bedrock. The site is in an area of low rolling topography, with elevations ranging from 480 feet above mean sea level (AMSL) at Thicketty Creek (figure 3), to 700 feet AMSL at the site itself, to 814 feet at a Bench Mark located approximately 1.4 miles northeast of the site.



LOCATION OF MEDLEY SITE, CHEROKEE COUNTY, S.C.

FIGURE 1

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PURPOSE

The Region IV FIT was tasked by EPA to conduct a geological and geophysical study of the Medley Site during the week of August 1, 1983. The purpose of the study was to determine whether the potential for ground-water contamination exists at the site. The objectives of the study were fourfold: (1) to characterize the site-specific geology and hydrology, (2) to determine if buried drums are present, (3) to determine if there is a subsurface contamination plume, and (4) to determine, if possible, the extent of such plume. To accomplish these objectives, the FIT first conducted a literature search on the geology and hydrology of the area, and performed a field study of the site vicinity employing standard geologic methods. The field study also included a geophysical survey which consisted of electrical resistivity soundings, a magnetometer survey, and an electromagnetometer survey. The site was gridded on 25-foot intervals. Electromagnetometer readings were taken at each grid node, or station, and also along continuous traverses. Readings between grid nodes were recorded if measurements indicated possible anomalies. Magnetometer readings were recorded for each grid node. Offsite background readings were obtained for all three methods prior to beginning the onsite survey.

GEOLOGY

Three physiographic provinces are found in South Carolina: the Atlantic Coastal Plain, which underlies approximately the southeastern half of the State; the Piedmont province, occupying the northwestern half; and the Blue Ridge province, underlying a narrow band in the northwesternmost part of the State.

Cherokee County is in the Piedmont physiographic province. This province is characterized by fractured and faulted igneous and metamorphic rocks of Precambrian and Paleozoic age. These crystalline rocks are grouped into six northeast-trending lithologic belts which are interpreted to be zones of different grades of regional metamorphism (Overstreet and Bell, 1965). The belts are, from southeast to northwest: the Carolina slate belt, the Charlotte belt, the Kings

Mountain belt, the Inner Piedmont belt, the Brevard belt, and the Blue Ridge belt (see figure 2).

The site is in the Kings Mountain belt, which consists of metasedimentary and metavolcanic rocks of low to moderate metamorphic grade. Rock types include schists, quartzite, marble, gneiss, and granite, with minor units of soapstone, pyroxenite, and mafic rocks. Rocks in the Kings Mountain belt reflect an episode of Carboniferous- to Permian-age metamorphism of sedimentary rocks. Metamorphism was accompanied by folding, fracturing, intrusion of cross-cutting granites, and the upgrading of earlier formed minerals along granite contacts (Overstreet and Bell, 1965, p. 114).

No rock outcrops have been observed at the site or in the immediate vicinity. However, according to a map published in 1965 by Overstreet and Bell, the specific rock types underlying the site are hornblende gneiss and quartz monzonite. The scale of that map is very small, so this may not be entirely accurate. Regional strike of the rocks is to the northeast and regional dip is southeast.

SOILS

Soils in Cherokee County are primarily residual soils (saprolite) derived from in-situ weathering of the underlying bedrock. This soil layer, or overburden, varies in thickness. It is thinner on hilltops where erosion has been most active, and thicker in valleys, where less erosion and more deposition has occurred. The site is on a ridgetop, but erosion has incised valleys, or gulleys, to very near the site.

HYDROLOGY

There are two "aquifer" systems in the Piedmont. One is in the overburden soil and weathered rock zone, termed by some workers as the "surficial" aquifer. The soil zone in the Piedmont is typicially a fairly tight clay, and water supplies are usually marginal at best. Since low yields are characteristic of this zone, large diameter bored or dug wells are typically installed in this zone (Workman and Sofge, 1983).

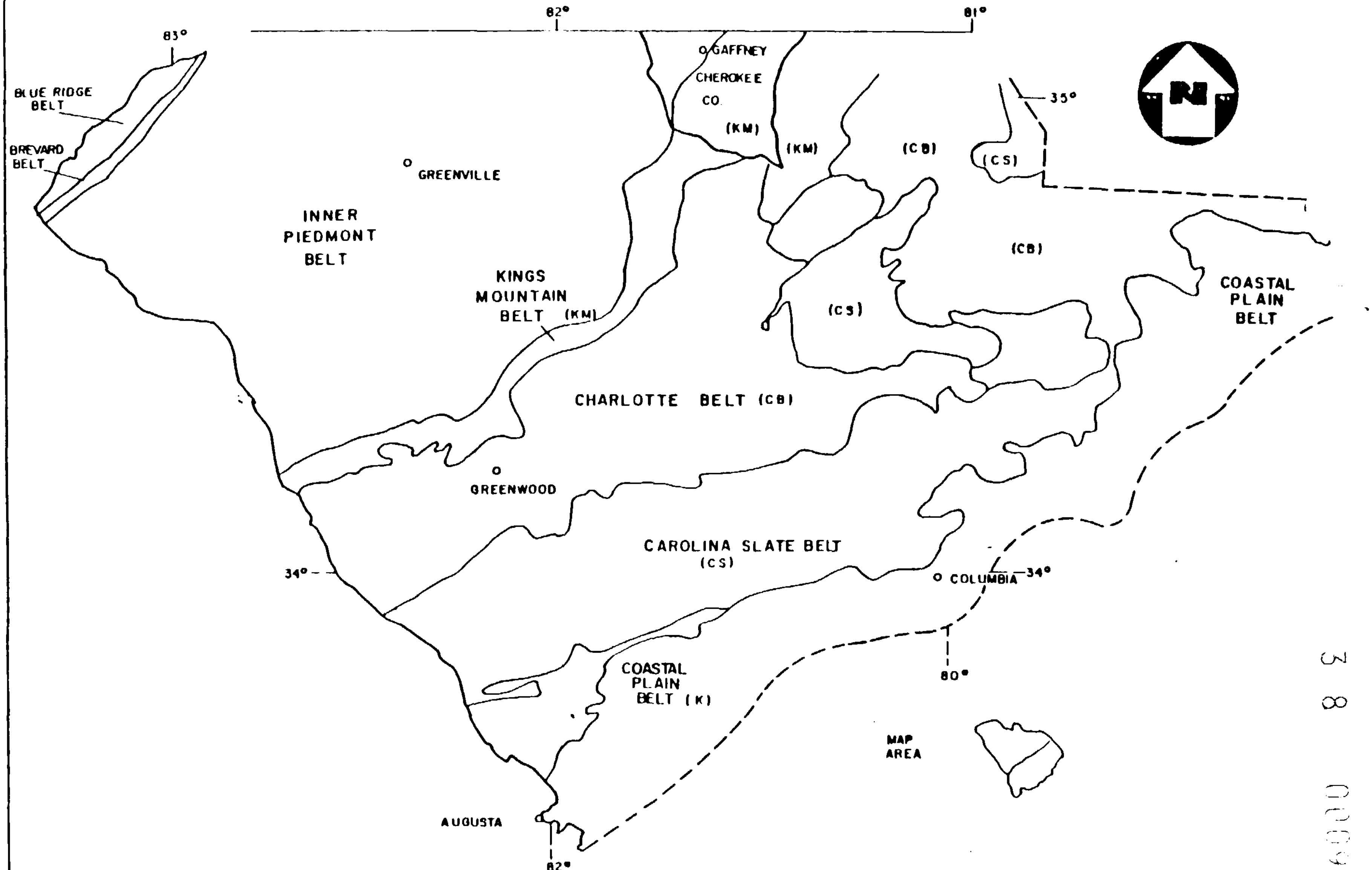

FIGURE 2

LITHOLOGIC BELTS OF SOUTH CAROLINA PIEDMONT
(FROM OVERSTREET AND BELL, 1965)

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Crystalline rock underlies the soil and weathered rock, and forms what is locally called the Igneous and Metamorphic Aquifer System (Workman and Sofge, 1983). Fractures determine zones of weakness in these crystalline rocks and control the movement of ground water (Dennis, 1972, p. 241). Fractures along which there has been no movement or negligible movement of the rocks are called "joints". It is likely that the type of fractures seen in the Piedmont is due to jointing. The following description of ground water occurrence in crystalline rocks is from a report by the South Carolina Department of Health and Environmental Control (DHEC) dated July, 1983.

> Except for fracture zones, the crystalline rocks are nearly impermeable. It is these fracture zones which provide the greatest permeability, and therefore the greatest quantities of ground water. Higher well yields (and)increased productivity is dependent upon the number and characteristics of the fractures intercepted. (Locations of major)fracture traces have been indicated on figure 3. It is along these traces that ground water flows and where contaminated ground water is likely to migrate.

Figure 3 is a portion of the Wilkinsville USGS 7½" Quadrangle with the Medley site located on it. Heavy lines represent possible fracture zones which are indicated by linear surface features called lineaments. There appear to be relatively few fracture traces and these are widely spaced. However, those shown are only the traces that have prominent enough surface expression to be indicated on a 1:24,000 topographic map. There are probably many smaller, more closely-spaced fracture zones that do not have obvious surface expression at this scale.

There are two sets of lineaments in the area. The most prominent set is indicated by long (1/3 mile to greater than one mile) erosional features that trend north-northeast. A less prominent set has produced shorter and less pronounced lineaments that range from one mile or less in length and trend generally north-northwest. Surface drainage follows the fracture patterns and has resulted in a drainage pattern that has features of both dendritic and trellis patterns.

As part of the hydrologic investigation by S.C. DHEC in June, 1983, water level measurements were recorded for four domestic wells in the vicinity of the site.

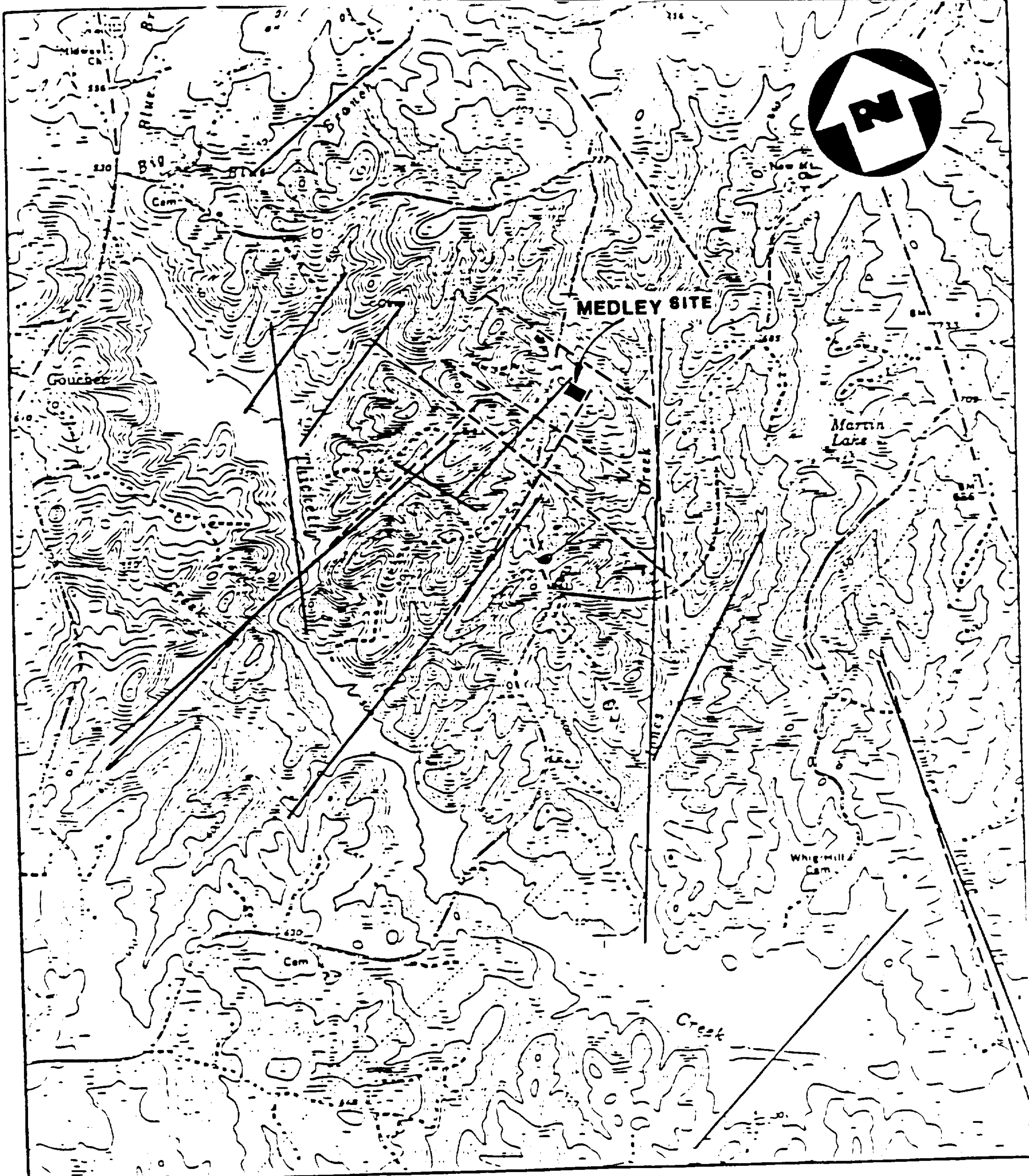

FIGURE 3

FRACTURE TRACES IN VICINITY OF MEDLEY SITE, GAFFNEY, SOUTH CAROLINA.

(U.S.G.S. PACOLET MILLS 7 1/2' QUADRANGLE MAP).

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Locations of the wells are shown on figure 3. All four wells are 24-inch bored wells, probably installed to the top of bedrock. Table 1 summarizes field data collected on these wells (from Workman and Sofge, 1983). Well depths were not recorded. However, depths of large diameter wells in this area are normally 10-20 feet below the water-table surface. As of mid-July, chemical analyses of the wells had not been received by DHEC. However, the specific conductance of water from the wells did not indicate the presence of contamination. If some of these wells are located near fractures and the ground water is or becomes contaminated, it is possible that these wells could become contaminated (Workman and Sofge, 1983).

GEOPHYSICAL SURVEY

Methods

Electromagnetometer Survey

The electromagnetometer survey was conducted using a Geonics EM-31 Non-contacting Terrain Conductivity Meter. Electromagnetometry provides a measure of subsurface electrical conductivity (the reciprocal of resistivity), which is a function of the basic soil or rock matrix, its pore space, and the fluids within the matrix (Benson & Glaccum, 1979). Conductivity measurements were taken at 288 stations corresponding to grid nodes. In addition, eleven readings were taken between grid nodes to more precisely delineate suspected anomalies.

Magnetometer Survey

The magnetometer survey was conducted using a GeoMetrics Unimag Proton Magnetometer, Model G-846. The purpose of the magnetometer survey was to ascertain if there are buried drums at the site. Magnetometer readings were taken at the same 288 stations as the EM measurements. Background magnetism in the area is 53,500 $\pm$ 400 gammas. Readings less than 53,100 gammas or greater than 53,900 gammas were considered anomalous.

TABLE 1. Well Data From Vicinity of Medley Site, Gaffney, South Carolina

Well	Water level from top of casing (in feet)	Specific Conductance (umhos/cm)	Temperature (°C)	Type of Well
Sprouse	36.52	25	21	Bored, 24 inch diameter
Sarrett	58.80	60	18	Bored, 24 inch diameter
Davis	67.00	25	18	Bored, 24 inch diameter
Pittman	26.07	25-35	19	Bored, 24 inch diameter

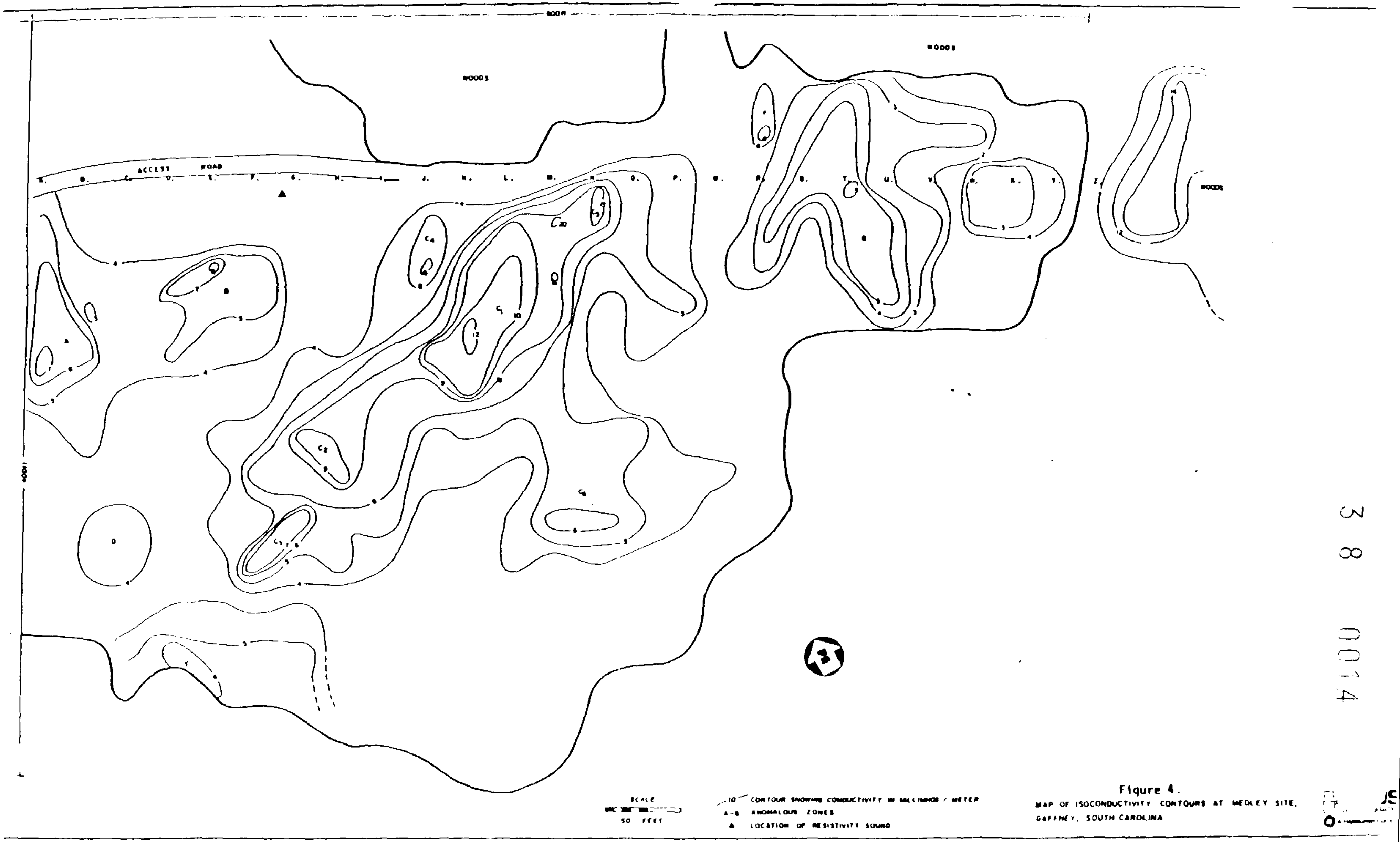


Figure 4.

MAP OF ISOCONDUCTIVITY CONTOURS AT MEDLEY SITE, GAFFNEY, SOUTH CAROLINA

3 8 0014

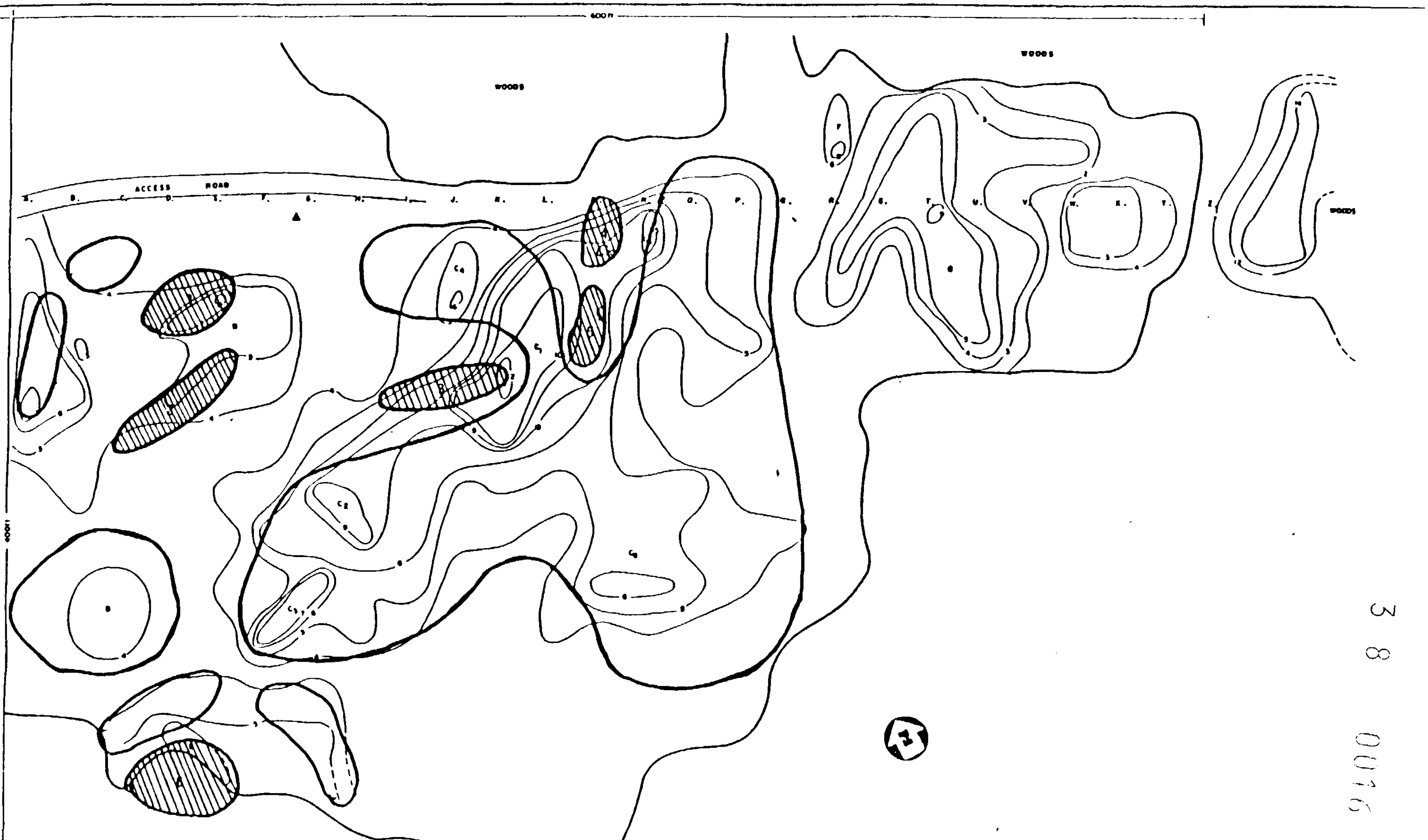
The central portion of Zone E was a lagoon, and the outer parts of Zone E were drum storage areas. Drums were also stored over the entire area extending from Zone G to C_6. Some contaminated soil remains onsite, and some of that the anomalous zones may indicate subsurface contamination. This is especially likely in view of the fact that offsite conductivities were 1 or 2 mmhos/m except in the area to the southeast, topographically downgradient of the site. This area, indicated on the right side of the map on figure 2 as a wooded area, appears to be undisturbed. The EM survey showed conductivities of 6 to 14 mmhos/m for several hundred feet from the site to the southeast, with greatest conductivity nearest the site. It appears that subsurface contamination may be migrating in this downgradient direction, or that rainfall may have carried surface contaminants downslope towards or across this area, which is also the direction of dip of the rocks.

Magnetometer Survey

Two small, magnetically anomalous areas were found during the field study (figure 6). The larger zone corresponds to the EM anomaly indicated as C_5, which was also the area showing the greatest conductivity (most intense anomaly). The entire remainder of the site had magnetometer readings approximately the same as background.

Electrical Resistivity

Electrical resistivity soundings curves indicate subsurface features at approximately 15 feet and 60 feet below land surface. The feature at 15 feet may be a perched water zone. The feature at 60 feet may be either a water-bearing fracture, or may indicate a transition from weathered to unweathered bedrock. It also may be a water-bearing zone, which could be due to water collecting above the relatively impermeable unweathered bedrock. Without stratigraphic data from any nearby wells, it is not possible to determine exactly what the features are.



Approximate location of former drum storage area

Approximate location of former lagoon

SCALE

50 FEET

10 CONTOUR SHOWING CONDUCTIVITY IN MILLIMHOS / METER

A-G ANOMALOUS ZONES

LOCATION OF RESISTIVITY SOUND

Figure 2a

MAP OF ISOCONDUCTIVITY CONTOURS AT MEDLEY SI

GAFFNEY, SOUTH CAROLINA

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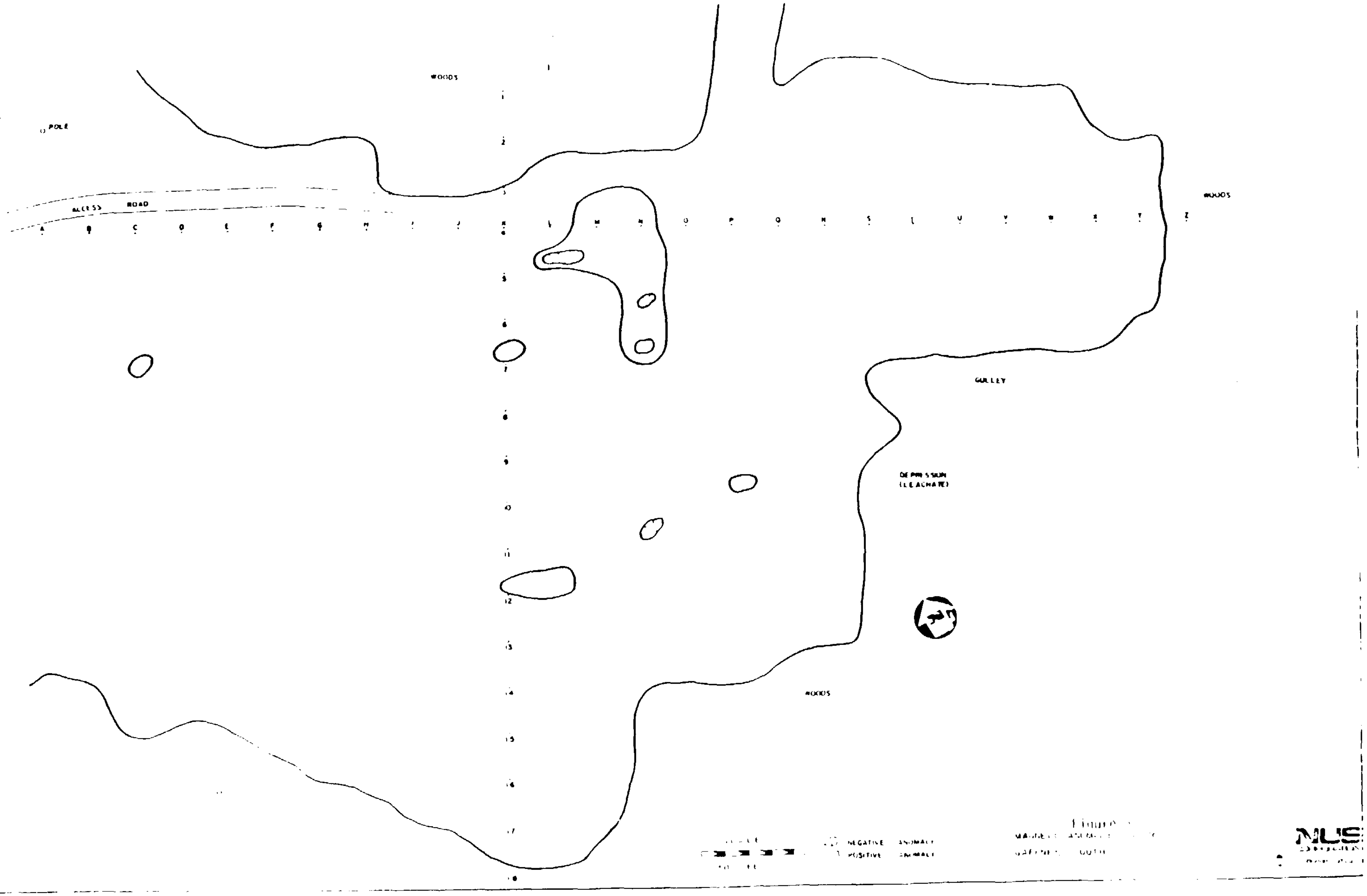


POLE
ACCESS ROAD
WOODS
WOODS
GULLEY
DEPRESSION
(LEACHATE)
WOODS
NEGATIVE ANOMALY
POSITIVE ANOMALY
NUS

CONCLUSIONS

The Medley Site is located in the Piedmont physiographic province, an area characterized by fractured and faulted metamorphic and igneous rocks. A geophysical survey of the site obtained data using electromagnetometer profiling, magnetometer measurements, and electrical resistivity soundings. Anomalous zones are shown on figures 4 and 6 respectively. These zones could be due to subsurface soil contamination, disturbance of natural soils, backfilled lagoons, or buried drums, although the magnitude of the anomalies indicate buried drums are not likely except in one small area. Former surface storage of leaking chemical waste containers, the use of lagoons for disposal of liquid wastes at the site, and soil contamination observed by FIT during this study, indicate that surface and subsurface soil contamination is the likeliest cause for the anomalies. FIT cannot estimate the depth of soil contamination.

Topographic lineaments in the vicinity are probably the surface expression of fracture traces. Such traces may provide conduits for ground water and contaminants to migrate. Wells located in or near fracture traces in the site vicinity may become polluted by contaminants originating from the site. It is not known how fast or how far contaminants can move in this type of hydrologic system. However, geophysical data indicate subsurface contaminants may have migrated as much as several hundred feet to the southeast, which is topographically downgradient and also the direction of dip of the rocks. The contaminants are most likely confined to the soil layer which overlies more impermeable bedrock.

References

Benson, R.C. and R.A. Glaccum, 1979, Remote assessment of pollutants in soil and groundwater, presented at the Hazardous Material Risk Assessment Disposal and Management Conference, Miami Beach, Florida, 1979.

Overstreet, W.C., and Henry Bell III, 1965, The crystalline rocks of South Carolina, USGS Bulletin 1183, 126 p.

Soiltest, Inc., Earth Resistivity Manual, 1979, Evanston, Ill., 52 p.

Workman, S.M., and Glenn Sofge, July, 1983, Memo to R.E. Malpass, Bureau of Solid and Hazardous Waste Management, on Medley Site, Cherokee County. South Carolina Department of Health and Environmental Control, Ground-Water Protection Division.

APPENDIX

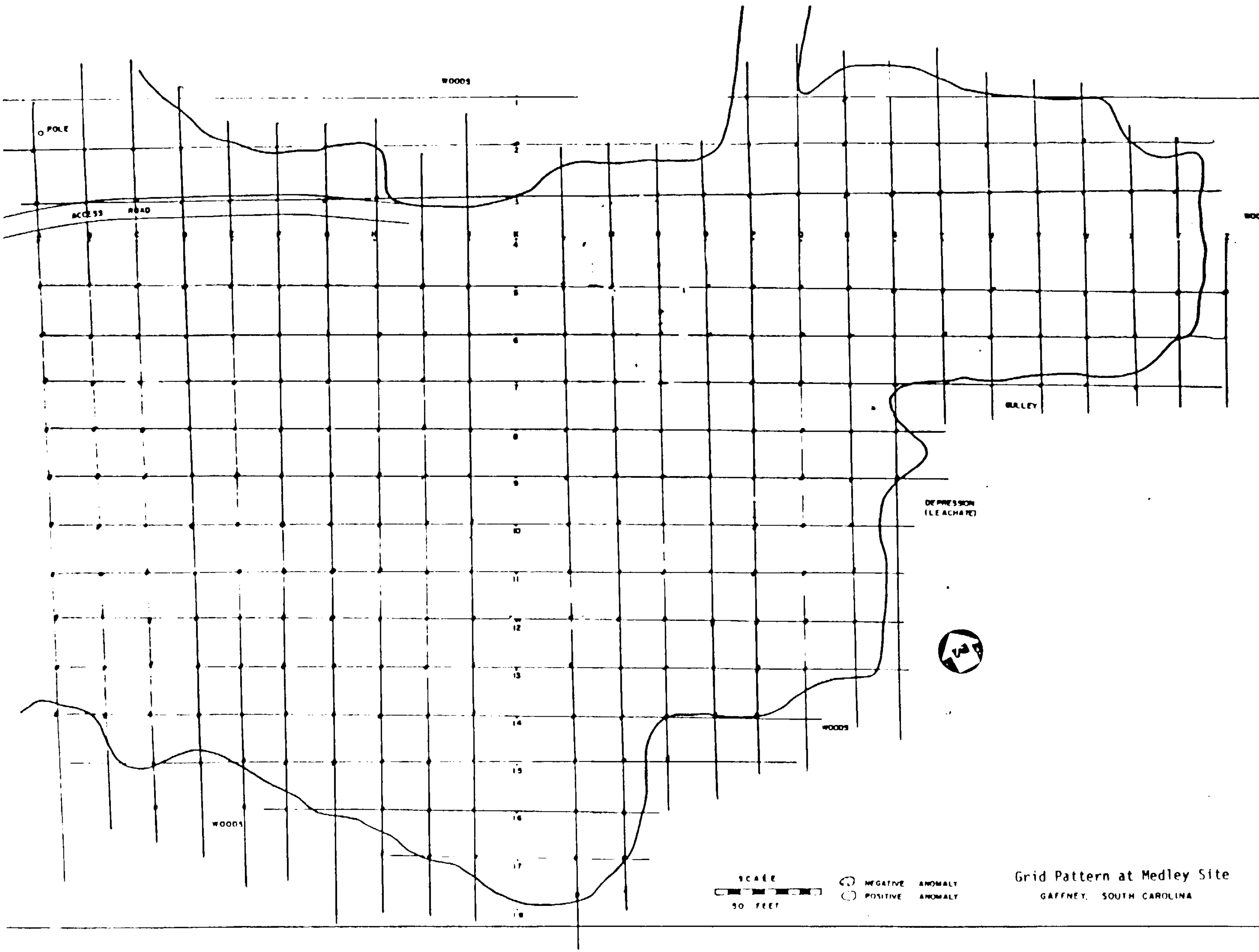
Grid pattern at Medley Site

Magnetometer field data

Electromagnetometer field data

Description of Magnetometer

Description of Electromagnetometer



Grid Pattern at Medley Site

GAFFNEY, SOUTH CAROLINA

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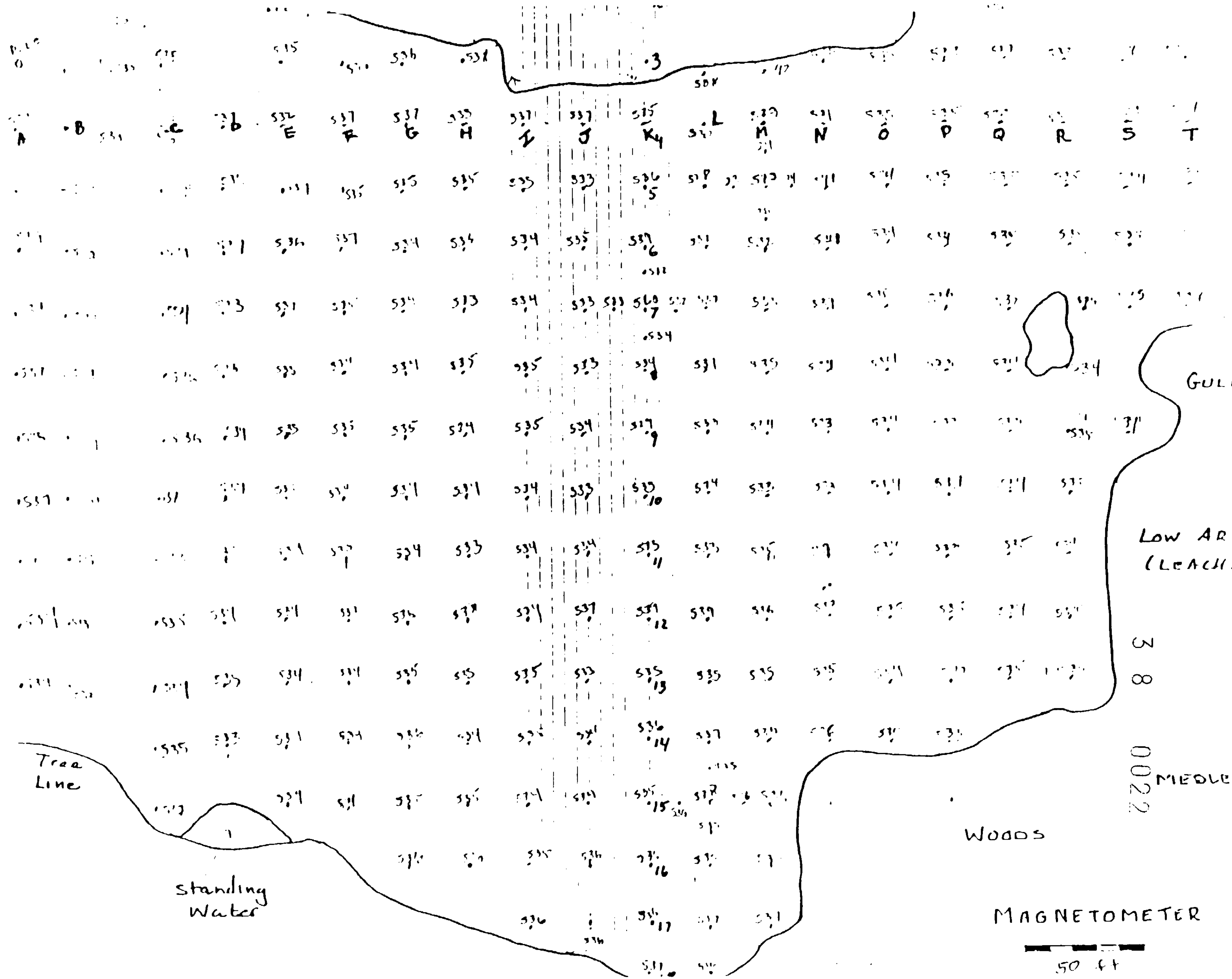
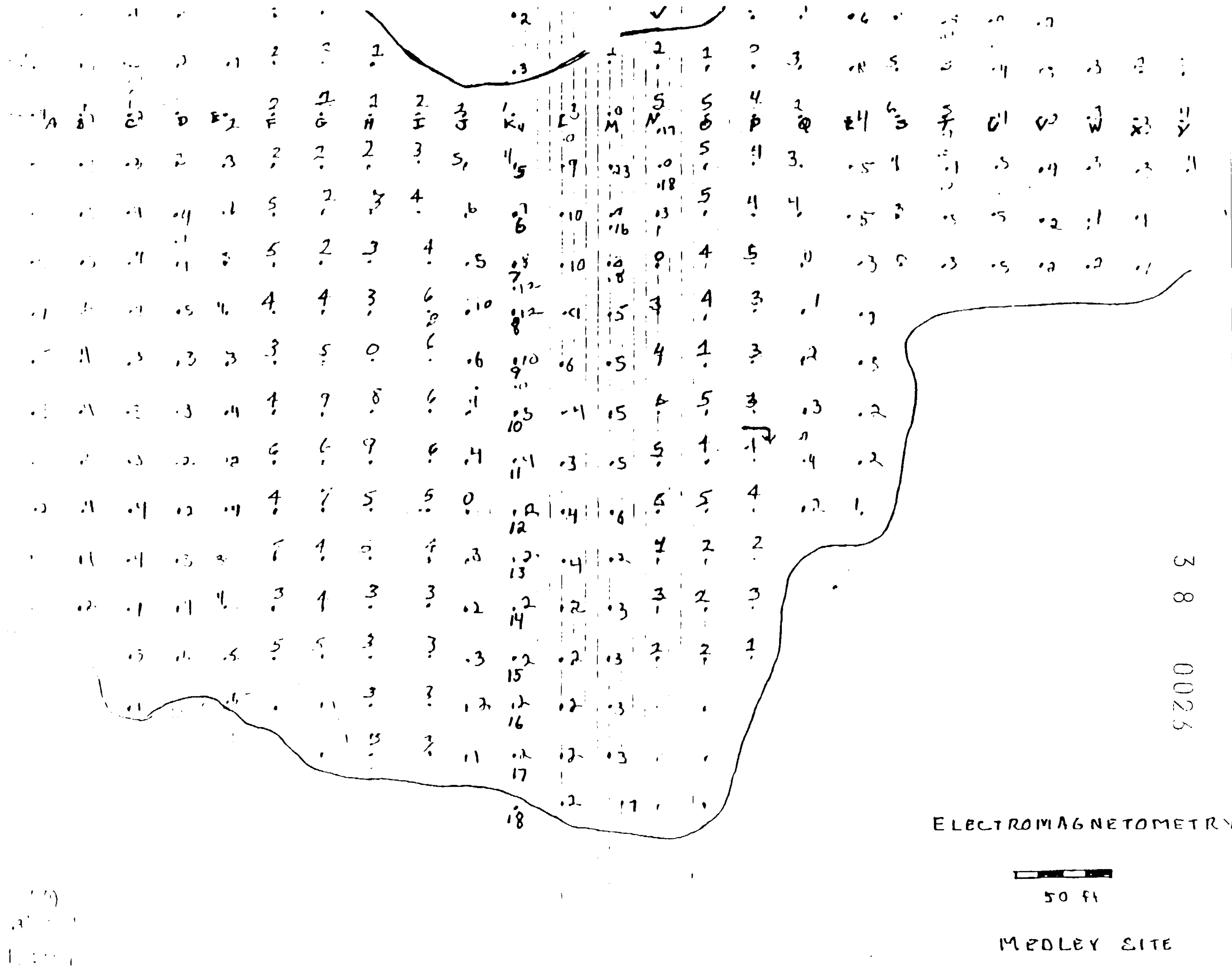

A B C D E F G H I J K L M N O P Q R S T
Tree Line
standing Water
WOODS
MAGNETOMETER
50 ft



38 0026
A B C D E F G H I J K L M N O P Q R S T U V W X Y
ELECTROMAGNETOMETRY
50 ft
MEDLEY SITE

The following sections are from "Geophysical Technique for Sensing buried Wastes and Waste Migration" by Glaccum, R. A., and M. R. Noel, August, 1983, Technos, Inc., for Environmental Monitoring Systems Laboratory, ORD, USEPA, Las Vegas, - 236 p.

APPENDIX

The following sections are from "Geophysical Technique for Sensing Buried Wastes and Waste Migration" by Glaccum, R. A., and M. R. Noel, August, 1983, Technos, Inc., for Environmental Monitoring Systems Laboratory, ORD., USEPA, Las Vegas, 236 P.

RESISTIVITY

The resistivity method is used to measure the electrical resistivity of the geohydrologic section which includes the soil, rock and ground water. Accordingly, the method may be used to assess lateral changes and vertical cross sections of the natural geohydrologic settings. In addition, it can be used to evaluate contaminant plumes and locate buried wastes at hazardous waste sites.

Application of the method requires that an electrical current be injected into the ground by a pair of surface electrodes. The resulting potential field (voltage) is measured at the surface between a second pair of electrodes. The subsurface resistivity can be calculated by knowing the electrode separation and geometry of the electrode positions, applied current, and measured voltage. (Resistivity is the reciprocal of conductivity, the parameter directly measured by the EM technique).

In general, most soil and rock minerals are electrical insulators (highly resistive); hence the flow of current is conducted primarily through the moisture-filled pore spaces within the soil and rock. Therefore, the resistivity of soils and rocks is predominantly controlled by the porosity and permeability of the system, the amount of pore water, and the concentration of dissolved solids in the pore water.

The resistivity technique may be used for "profiling" or "sounding". Profiling provides a means of mapping lateral changes in subsurface electrical properties. This field technique is well suited to the delineation of contaminant plumes and the detection and location of changes in natural geohydrologic conditions. Sounding provides a means of determining the vertical changes in subsurface electrical properties. Interpretation of sounding data provides the depth and thickness of subsurface layers having different resistivities. Commonly up to 4 layers may be resolved with this technique. 3 8 0026

Applications of the resistivity method at hazardous waste sites include:

- Locating and mapping contaminant plumes;
- Establishing direction and rate of flow of contaminant plumes;
- Defining burial sites by
  - locating trenches,
  - defining trench boundaries,
  - determining the depths of trenches.
- Defining natural geohydrologic conditions such as
  - depth to water table or to water-bearing horizons,
  - depth to bedrock, thickness of soil, etc.

Most dry mineral components of soil and rock are highly resistive except for a few metallic ore minerals. Under most circumstances, the amount of soil/rock moisture dominates the measurement greatly reducing the resistivity value. Current flow is essentially electrolytic, being conducted by water contained within pores and cracks. A few minerals like clays actually contribute to conduction. In general, soils and rocks become less resistive as:

- Moisture or water content increases;
- Porosity and permeability of the formation increases;
- Dissolved solid and colloid (electrolyte) content increases;
- Temperature increases (a minor factor, except in areas of permafrost).

Very dry sand, gravel or rock as encountered in arid or semi-arid areas will have very high resistivity. As the empty pore spaces fill with water, resistivity will drop. Conversely, the resistivity of earth materials which occur below the water table but lack pore space (such as massive granite and limestone) will be relatively high and will be primarily controlled by current conduction along cracks and fissures in the formation. Clayey soils and shale layers generally have low resistivity values, due to their inherent moisture and clay mineral content. In all cases, an increase in the electrolyte, total dissolved solids (TDS) or specific conductance of the system will cause a marked increase in current conduction and a corresponding drop in resistivity. This fact makes resistivity an excellent technique for the detection and mapping of conductive contaminant plumes.

The operator must insure that adequate space is available at the site and that it is relatively clear of buried pipes and fences. Finding sufficient space for a long profile array with an overall length three to six times the depth of interest, or a sounding array with an overall length nine to twelve times the depth of interest can sometimes be a problem.

Although resistivity sounding methods are primarily intended for use in uniformly layered geological conditions, useful data may be obtained from the complex subsurface conditions often found at HWS. With both profiling and sounding techniques, inhomogeneities in the near-surface soils may introduce noise in the data. Some surface conditions such as dry surface materials, concrete roads or parking lots may preclude the use of the resistivity method.

The resistivity method is inherently limited to station measurements, since electrodes must be in physical and electrical contact with the ground. This requirement makes the resistivity method slower than a non-contact method such as EM.

Capabilities

- o Resistivity profiling techniques can be used to detect and map contaminant plumes and changes in geohydrology.
- o Resistivity sounding methods can estimate the depth, thickness and resistivity of subsurface layers, or depth to the water table.
- o Both profiling and sounding data can be evaluated qualitatively or semi-quantitatively in the field.

- o Resistivity values can be used to identify the probable geologic composition of a layer or to estimate the specific conductance of a plume
- o Depth to bottom of landfills and large burial sites can sometimes be estimated.

Limitations

- o The sounding technique requires that site conditions be relatively homogeneous laterally.
- o The method is susceptible to noise caused by nearby fences, pipes and geologic scatter, which may interfere with usefulness of the data.
- o Quantitative interpretation requires the use of master curves and/or computer programs, and experience in their use.

ELECTROMAGNETICS (EM)*

The electromagnetic (EM) method provides a means of measuring the electrical conductivity of subsurface soil, rock and ground water. Electrical conductivity is a function of the type of soil and rock, its porosity, its permeability and the fluids which fill the pore space. In most cases the conductivity (specific conductance) of the pore fluids will dominate the mesurement. Accordingly, the EM method is applicable both to assessment of natural geohydrologic conditions and to mapping of many types of contaminant plumes. Additionally, trench boundaries, buried wastes and drums, as well as metallic utility lines can be located with EM techniques.

Natural variations in subsurface conductivity may be caused by changes in soil moisture content, ground water specific conductance, depth of soil cover over rock, and thickness of soil and rock layers. Changes in basic soil or rock types, and structural features such as fractures or voids may also produce changes in conductivity. Localized deposits of natural organic, clay, sand, gravel, or saltrich zones will also affect subsurface conductivity.

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*The term electromagnetic has been used in contemporary literature as a descriptive term for other geophysical methods, including GPR and metal detectors which are based on electromagnetic principles. However, this document will use electromagnetic (EM) to specifically imply the measurement of subsurface conductivities by low-frequency electromagnetic induction. This is in keeping with the traditional use of the term in the geophysical industry from which the EM methods originated. While the authors recognize that there are many electromagnetic systems and manufacturers, the discussion in this section is based solely on instruments which are calibrated to read in electrical conductivity units and which have been effectively and extensively used at hazardous waste sites. There is only one manufacturer of such instruments at the time of this writing.

Many contaminants will produce an increase in free ion concentration when introduced into the soil or ground water systems. This increase over background conductivity enables detection and mapping of contaminated soil and ground water at HWS, landfills and impoundments. Large amounts of organic fluids such as diesel fuel can displace the normal soil moisture, causing a decrease in conductivity which may also be mapped, although this is not commonly done. The mapping of a plume will usually define the local flow direction of contaminants. Contaminant migration rates can be established by comparing measurements taken at different times.

The absolute values of conductivity for geologic materials (and contaminants) are not necessarily diagnostic in themselves, but the variations in conductivity, laterally and with depth, are significant. It is these variations which enable the investigator to rapidly find anomalous conditions.

Since the EM method does not require ground contact, measurements may be made quite rapidly. Lateral variations in conductivity can be detected and mapped by a field technique called profiling. Profiling measurements may be made to depths ranging from 0.75 to 60 meters. Instrumentation and field obtain continuous EM profiling data to a depth of 15 meters. The data is recorded using strip chart and magnetic tape recorders. This continuous measurement allows increased rates of data acquisition and improved resolution for mapping small geohydrologic features. Further, recorded data enhanced by computer processing has proved invaluable in the evaluation of complex hazardous waste sites. The excellent lateral resolution obtained from EM profiling data has been used to advantage in efforts to outline closely-spaced burial pits, to reveal the migration of contaminants into the surrounding soil, or to delineate fracture patterns.

Vertical variations in conductivity can also be detected by the EM method. A station measurement technique called sounding is employed for this purpose. Data can be acquired from depths by combining results from a variety of EM instruments, each requiring different field application techniques. Other EM systems are capable of sounding to depths of 1000 feet or more, but have not yet been used at HWS and are not adaptable to continuous measurements.

Profiling is the most cost-effective use of the EM method. Continuous profiling can be used in many applications to increase resolution, data density and permit total site coverage at critical sites.

At HWS, applications of EM can provide:

- o Assessment of natural geohydrologic conditions;
- o Locating and mapping of burial trenches and pits containing drums and/or bulk wastes;
- o Locating and mapping of plume boundaries;
- o Determination of flow direction in both unsaturated and saturated zones;
- o Rate of plume movement by comparing measurement taken at different times;
- o Locating and mapping of utility pipes and cables which may affect other geophysical measurements, or whose trench may provide a permeable pathway for contaminant flow.

Although there is available a wide variety of EM equipment, most of it is intended for geophysical exploration of mineral deposits. These units have not been used at HWS and do not provide a simple conductivity reading. This document discusses only those instruments which are designed and calibrated to red directly in units of conductivity.

The basic principle of operation of the electromagnetic method is shown in Figure _____. The transmitter coil radiates an electromagnetic field which induces eddy currents in the earth below the instrument. Each of these eddy current loops, in turn, generates a secondary electromagnetic field which is proportional to the magnitude of the current flowing within th at loop. A part of the secondary magnetic field from each loop is intercepted by the receiver coil and produces an output voltage which (within limits) is linearly related to subsurface conductivity. This reading is a bulk measurement of conductivity; the cumulative response to subsurface conditions ranging all the way from the surface to the effective depth of the instrument.

The sampling depth of EM equipment is related to the instrument's coil spacing. Instruments with coil spacings of 1, 4, 10, 20 and 40 meters are commercially available. The nominal sampling depth of an EM system is taken to be approximately 1.5 times the coil spacing.

The EM sounding method can rarely identify more than 2 or 3 layers with reasonable confidence. The greater the contrast in the conductivity values of each layer, the better the results. Often, the more detailed resistivity sounding method is used to complement EM profiling data.

The results of sounding analysis are usually presented as a vertical section, in which the conductivity layers are identified as a function of depth. The analyst may be able to correlate these layers to geohydrologic units believed to exist at the site.

Although the EM technique can be used for profiling or sounding, profiling is the most effective use of the EM method. Profiling makes possible the rapid mapping of subsurface conductivity changes, and the location, delineation and assessment of spatial variables resulting from changes in the natural setting or from many contaminants.

EM is a very effective reconnaissance tool. The use of qualitative non-recorded data can provide initial interpretation in the field. If site conditions are complex, the use of a high-density survey grid, continuously-recording instruments, and computer processing may be necessary, in order to properly evaluate subsurface conditions. When continuously-recording instruments are used, total site coverage is feasible. More quantitative information can be obtained by using conductivity data from different depth ranges. At present, three different systems must be used to acquire data from 0.75 meters to 60 meters. Very often, however, data from two standard depths, e.g. 6 and 15 meters, is adequate to furnish depth information.

Capabilities

- o The EM profile method permits rapid data acquisition, resulting in high-density and high-resolution surveys.
- o Profiling data may be acquired from various discrete depths, ranging from 0.75 meters to 60 meters.
- o Continuously-recording instruments (to 15 meter depth) can increase survey speed, density and resolution permitting total site coverage, if required.
- o EM reads directly in conductivity units (mm/m) permitting use of raw data in the field, and correlation to specific conductance of ground water samples.
- o EM can map local and general changes in the natural geohydrologic setting.
- o EM can detect and measure the boundaries of a conductivity plume.
- o Direction of plume flow can be determined from an EM conductivity map.
- o EM measurments taken at different times can provide the means to compute movement rates of conservative contaminants.
- o EM can detect and map burial pits and trenches of both bulk and drummed wastes.
- o EM can detect and map the location of buried metallic utility lines.

Limitations

- o EM has less sounding (vertical) resolution than the resistivity method, due to its limited number of depth intervals.
- o The acquisition of data from depths of 0.75 to 60 meters requires the use of three differenct EM systems.
- o Continuous data can be obtained only to depths up to approximately 15 meters.
- o An EM measurement is influenced by the shallower materials more than the deeper ones; this must be considered when evaluating the data.
- o EM measurements become non-linear in zones of very high conductivity.

- The EM method is susceptible to noise from a number of sources, including natural atmospheric noise, powerlines, radio transmitters, buried metallic trash, pipes, cables, nearby fences, vehicles and buildings.

MAGNETOMETER

Magnetic measurements are commonly used to map regional geologic structure and to explore for minerals. They are also used to locate pipes and survey stakes or to map archeological sites. They are commonly used at HWS to locate buried drums and trenches.

A magnetometer measures the intensity of the earth's magnetic field. The presence of ferrous metals creates variations in the local strength of that field, permitting their detection. A magnetometer's response is proportional to the mass of the ferrous target. Typically, a single drum can be detected at distances up to 6 meters, while massive piles of drums can be detected at distances up to 20 meters or more.

Some magnetometers require the operator to stop and take discrete measurements; other instruments permit the acquisition of continuous data as the magnetometer is moved across the site. This continuous coverage is much more suitable for high resolution requirements and the mapping of extensive areas.

The effectiveness of a magnetometer can be reduced or totally inhibited by noise or interference from time-variable changes in the earth's field and spatial variations caused by magnetic minerals in the soil, or iron and steel debris, ferrous pipes, fences, buildings, and vehicles. Many of these problems can be avoided by careful selection of instruments and field techniques.

At HWS, magnetomenter may be used to:

- o Locate buried steel containers, such as 55-gallon drums;
- o Define boundaries of trenches filled with ferrous containers;
- o Locate ferrous underground utilities, such as iron pipes or tanks, and the permeable pathways often associated with them;
- o Select drilling locations that are clear of buried drums, underground utilities, and other obstructions.

A magnetometer measures the intensity of the earth's magnetic field. Variations in this field may be caused by the natural distribution of iron oxides within the soil and rock or by the presence of buried iron or steel objects. (The magnetometer does not respond to nonferrous metals such as aluminum, copper, tin, and brass.)

The earth's magnetic field behaves much as if there were a large bar magnet embedded in the earth. Although the earth's field intensity varies considerably throughout the United States, its average value is approximately 50,000 gammas.* surface also varies. In the U.S., this angle of inclination ranges approximately 60 to 75 degrees form the horizontal.

The intensity of the earth's magnetic field changes daily with sunspots and ionospheric conditns which can cause large and sometimes rapid variations. With time, these variations produce unwanted signals (noise) and can substantially affect magnetic measurements.

If the magnetic properties of the soil and rock were perfectly uniform, there would be no local magnetic anomalies; however, a concentration of natural iron minerals, or a buried iron object, will cause a local magnetic anomaly which can be detected at the surface (Figure _____).

An example of a magnetic anomaly indication over buried drums is shown in Figure ____; the exact shape of which may vary considerably. Typical magnetic anomalies at HWS will range from one to hundreds of gammas for small discrete targets, depending on their depth. Massive piles of buried drums will result in anomalies fo from 100 to 1000 gammas or more.

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*The unit of magnetic measurement is the gamma. Recently, the gamma unit has been renamed the Nano Tesla. At this time, most instruments are still labeled in gammas as are specification sheets, existing literature and field data; hence, all references to magnetic data in this document are expressed in gammas.

While several factors influence the response of a magnetometer, the mass of a buried target and its depth are the most important. A magnetometer's response is directly proportional to the mass of ferrus metal present and varies by one over the distance cubed ($1/d^3$) for total field measurements. If a gradiometer is used, the response falls of even faster, as one over the distance to the fourth power ($1/d^4$). With sensors of equal sensitivity, the total field system provides the greater working range. Typically, a single drum can be detected at distances up to 6 meters, while massive piles of drums can be detected at distances up to 20 meters or more. There is wide variety of magnetometers available commerically; specific performance is highly dependent upon the type of magnetometer and the field conditions. While the number of drums may be calculated, such results should be considered only approximations because of the number of variable associated with targets, site conditions and calculations. Actual results may vary considerably.

A magnometer with continuous recording capabilities can be used to produce a strip chart of the field data, which is helpful in assessing signal-to-noise ratio, anomaly shape, and target location, and provides a means of exercising quality control over field data. This continuous coverage is much more suitable for high-resolution requirements and the mapping of extensive areas.

The effectiveness of a magnetometer can be reduced or totally inhibited by noise or interference from time-variable changes in the earth's field and spatial variations caused by magnetic minerals in the soil, or iron and steel debris, ferrous pipes, fences, buildings, and vehicles. Many of these problems can be avoided by careful selection of instruments and field techniques.

Capabilities

- Magnetometers respond to ferrous metals (iron or steel) only.
- Individual drums can be detected at depths up to 6 meters.
- Large masses of drums can be detected at depths of 6 to 20 meters.
- Magnetometers can provide a greater depth range than metal detectors.
- Interpretations of their data may be used to provide estimates of the number and depth of buried drums.

- They can provide a continuous response along a traverse line.
- They may be mounted on vehicles for coverage of a large site.

Limitations

- In general, magnetometers are susceptible to noise from many different sources, including steel fences, vehicles, buildings, iron debris, natural soil minerals and underground utilities.
- Low cost units are limited in depth range (but their limitations make them insensitive to many of the above sources of noise).
- Total field instruments are also sensitive to fluctuations in the earth's magnetic field which can seriously affect data.
- Data is of limited use in determining the number and depth of targets.
- Complex site conditions may require the use of highly skilled operators, special equipment, and the recording and processing of data, along with skilled interpretation.